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Revolutionizing Agriculture Soil Testing with Agriculture 4.0 and IoT Integration

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Abstract

The introduction of "Agriculture 4.0," which transforms traditional farming processes through the integration of digital technology and the Internet of Things (IoT), has made a huge impact on the agriculture business. In modern agriculture, soil testing is an indispensable component that plays a major role in increasing crop yields, minimizing environmental impact, and advancing sustainable agricultural practices. This paper presents a comprehensive study on how Agriculture 4.0 and IoT technologies are used in revolutionizing the process of agriculture soil testing. A new era in the collection, analysis, and application of data in agriculture is brought about by Agriculture 4.0. With the help of an integration of advanced sensors, wireless connectivity, and cloud computing to create a robust IoT-based soil testing system. Such a system can continuously monitor soil parameters such as moisture content, pH levels, nutrient levels, and temperature in real-time, providing farmers with a wealth of data for decision-making. Farmers can access this data through user-friendly dashboards on their smartphones or computers, enabling them to make data-driven decisions regarding crop selection, irrigation scheduling, and nutrient management. Furthermore, the system can provide early warnings for soil health issues, helping farmers prevent potential crop losses. This paper also delves into the incorporation of machine learning and artificial intelligence algorithms with data from the Internet of Things (IoT). These technologies can analyze real-time soil testing data for Murbad, Bhivandi, Shahapur and Kalyan regions, to provide predictive insights, for the various soil properties like PH, EC, OC, N, P, Zn enabling to set the threshold values for the sensor used in precision agriculture and optimizing resource utilization. The use of machine learning algorithms will train the model to provide the optimal value recommendations for the application of fertilizers and pesticides, reducing input costs and minimizing environmental impact.

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Introduction

Agriculture is a primary source of animal and human foods, and current projection indicates that in with enough food in the twenty-first century, yields may need to increase by as much as 70%.[1,2] Agriculture 4.0, frequently referred to as "Smart Agriculture" or "AgriTech," is the process of integrating cutting-edge technologies into the agricultural industry to improve sustainability, production, and efficiency of crops in precision farming. Utilizing advancements in domains such as robots, artificial intelligence, data analytics, Internet of Things (IoT), and bIoTechnology, it signifies a revolutionary change in farming practices. Various key components like smart sensors and IoT, drones and Unmanned Aerial vehicles (UAVs), robotics and automation, data analytics and AI, vertical farming and Controlled Environment Agriculture (CEA) provide support to farmers with the most comprehensive and precise assistance possible when making decisions about their agricultural activities. The goal of agriculture 4.0 is to increase farming's sustainability, resilience, and profitability in the face of issues including population expansion, resource scarcity, climate change, and shifting customer preferences.

The agricultural landscape has been reshaped by the emergence of Agriculture 4.0, a phase highlighted by the convergence of advanced digital technologies and the Internet of Things (IoT).[22] Precision agriculture is a farming system technique that is computed for crop production based on field parameters such as low output, high efficiency, and well-balanced agriculture.[20] This computation is done along certain dimensions.[5-6] The current transformation has led to more efficient and sustainable farming practices, with the potential to revolutionize the way we approach agriculture soil testing. Soil testing is a cornerstone of modern farming, as it provides crucial insights into soil health and nutrient levels, ultimately guiding decisions related to fertilization, irrigation, and choice of crops.[22] The pH level, soil content, water level, humidity, and temperature can all be observed by the sensors that are part of the Wireless Sensor Network. IoT-based precision and agricultural farming is typically used to monitor the attached sensors for water volume, moisture, air quality, and humidity.[9]

Agriculture 4.0 and IoT technologies have opened new frontiers in this field, streamlining the process of soil testing and enhancing its precision.[6] The machine learning method yields better temporal and geographical data with little time consumption and shows higher analytical performance when compared to previous physical models.This paper explores how Agriculture 4.0 and the Internet of Things are integrating with soil testing in agriculture, highlighting the important advancements that are changing this crucial facet of farming in the twenty-first century. Farmers can access soil information concurrently and use it to make data-driven decisions that maximize crop yields and advance environmental sustainability by leveraging the power of advanced sensors, connected devices, and statistical analysis of various farming-related data.In this context, the upcoming sections will explore the technological developments and possible advantages of this integrated approach, emphasizing how Agriculture 4.0 and IoT have the potential to revolutionize the field of agricultural soil testing.

Motivation

Lack of education, real-time forecasting, automation, reach, and communication are the issues that traditional farming faces. Although technology has improved traditional soil testing, various data components must still be collected for precision farming's data processing. Several researchers' analyses and distinctions based on IoT-dependent Wireless Sensor Networks for the various protocols required in the development of realistic and accurate precision agricultural farming applications are reviewed. The difficulties that arise during the analysis and the obtained advantages in addition to the limitations are also included in this segment.

Literature Survey

The integration of Agriculture 4.0, which encompasses the use of digital technologies and the Internet of Things (IoT), into agriculture soil testing, has garnered significant attention in recent years. A variety of techniques to precision farming and agriculture are presented in the literature review.[2] Researchers have recognized the potential of this convergence to revolutionize soil testing processes and enable more precise and sustainable farming practices. IoT sensors that are scattered have a connection to robust computing resources due to modern agricultural systems that use the conventional cloud-based architecture. The processing, analysis, and cloud storage of heterogeneous data generated by multiple network layer transfer has placed a significant burden on information and communication infrastructure, due to the associated energy consumption costs. To be able to deal with these problems, an integrated edge-fog-cloud architectural paradigm is used in energy-efficient agriculture IoT (EEAIoT-EFC).[8] A literature survey reveals several key trends and insights in this domain.

IoT-Based Soil Sensors

IoT technology plays a pivotal role in real-time soil monitoring. Numerous studies have explored the development and deployment of IoT-based soil sensors that can measure critical parameters such as moisture content, pH levels, temperature, and nutrient levels.[8] These sensors offer advantages in terms of data accuracy, ease of installation, and remote monitoring capabilities.

LPWAN Based Wireless Communication

IoT technologies enable the collection of data from various agricultural components, such as soil, crops, and weather conditions, facilitating informed decision-making. In the context of soil testing, IoT provides the foundation for real-time monitoring of soil parameters critical for plant growth and yield. Low-Power Wide-Area Network (LPWAN) technologies, with their ability to provide long-range communication with minimal power consumption, are well-suited for agricultural applications.[24] LoRa (Long Range) technology, in particular, has gained prominence due to its low-cost, low-power characteristics, making it ideal for large-scale deployments in rural areas.

Data Analytics for Soil Health Assessment

Data analytics, including machine learning and artificial intelligence (AI), have become essential tools for processing and interpreting the vast amounts of data generated by IoT enabled soil sensors.[13] Researchers have developed algorithms to analyze this data for soil health assessment, early anomaly detection, and prediction of soil conditions. These data-driven insights are invaluable for farmers in making informed decisions.

Precision Agriculture

The integration of Agriculture 4.0 and IoT in soil testing aligns with the principles of precision agriculture.[2] By continuously monitoring and analyzing soil data, farmers can optimize re- source allocation, tailor crop management practices, and reduce waste. The literature emphasizes the potential of precision agriculture to enhance crop yield and sustainability.

Environmental Impact Mitigation

Agriculture 4.0 and IoT also offer tools to mitigate the environmental impact of farming.[23] By precisely controlling irrigation and nutrient application based on real-time soil conditions, these technologies can reduce overuse of water and fertilizers, minimizing environmental harm.

User-Friendly Interfaces

Researchers have recognized the importance of user-friendly interfaces for farmers. Many studies have highlighted the development of intuitive dashboards and mobile applications that allow farmers to access and interpret soil data easily, enabling quick decision-making in the field.

Review of literature relevant to the proposed module and various comparative models with prospect to soil testing and IoT. Both concepts provide a digital twin for proposed research work. All the review of several recent works with prose and cones are as follows:

Table 1: Comparative Table of Literature Survey

Ref. No	Author	Method	Advantages	Disadvantages
1	Eleni Symeonaki[14]	context-aware IoT agricultural system	It can be customized, modified, and expanded to suit any application within any precision farming system environment, regardless of its complexity.	The compatibility and systematization of the suggested framework are not well improved. (Air temp / Humidity)

2	chilles D. oursianis[13]	AREThOU5A IoT (LoRa WAN with random forest supervised algo)	Ensure workability by confirming that the voltage levels at the two operating frequencies are sufficient to power the sensor.	The output power and the voltage are needed to be improved (Single crop Apple).
3	R. Akhter, S. Ahmad Sofi[2]	Machine learning with IoT (incorp-orateAdaptive Neuro Fuzzy classifier of Neural network)	If the disease is accurately and promptly predicted, real-time measures against potential diseases such as scabs will be the approach. (Proposal)	The initial outlay for trai-ning, deployment, and implementation is substa-ntial. (Soil parameters are not use)
4	Sayan Kumar Roy and Debashis De[16]	Genetic algorithm based smart and intelligence system	It provides a system optimized for resource efficiency.	Computationally expensive and time-consuming. (Use for Rainfall)
5	Nermeen Gamal Rez[1]	Wrapper feature selection PART algorithm (Deep CNN)	Using random sampling, this approach has the benefit of minimizing bias in the training and testing datasets.	The future values are not observed previously. (reduction of crop produc-tivity not included)
6	Hatem A. Alharbi and Mohammad Aldossary[12]	Integrated edge-fog-cloud archite-ctural paradigm	Greatly decreased the quantity of data transferred to and from the cloud as well as the comp-uting burden.	Not implemented in a real agricultural environment.

Literature Analysis

Data Integration

Even though data analytics is widely studied, further research is necessary to fully understand how to integrate data from many sources.[10] A more comprehensive knowledge of soil health and its dynamic character can be obtained by combining soil data with meteorological information, satellite imaging, and other contextual data.

Standardization

Interoperability between IoT-based soil sensors and data analytics tools may be hampered by the absence of standard protocols and data formats. Encouragement of standardization initiatives is necessary to guarantee data sharing and compatibility between various devices and systems.[7]

Scalability

Small-scale deployments are the main focus of many current investigations. More investigation is required to determine whether Internet of Things-based soil testing systems can be scaled to meet the demands of big commercial farms while taking infrastructure constraints and cost-effectiveness into account.[15]

Environmental Monitoring

There is a need for a more thorough examination of the quantifiable environmental effects, such as decreased water use, greenhouse gas emissions, and soil degradation, even if some research mentions the environmental advantages of Agriculture 4.0 and IoT in soil testing.[7]

Farmer Adoption

It is crucial to do research on the variables influencing farmers' adoption of IoT-based soil testing procedures. Comprehending the obstacles and incentives can aid in the extensive integration of these technologies 16. The literature on Agriculture 4.0 related to soil testing using sensors and data analytics reflects a growing interest in this field. It highlights the potential for transformative changes in agriculture practices, emphasizing precision, sustainability, and data-driven decision-making.

Scope of Work

One of the key characteristics of Agriculture 4.0 is the capacity to control the degree, timing, and circumstances of exchanging one's physical, behavioral, or intellectual presence with others. One of the biggest issues in research nowadays is data analysis due to the increasing reliance on various digital devices such as computers, the internet, and smartphones. The objective of innovation in the agriculture sector is to design and implement a smart system that closes the technological gap between the development of farmers and their ability to expand economically. Allowing users to make effective use of these services while protecting data from exposure and interpretation during the analytics procedure. The purpose of this research is to develop and construct an intelligent Internet of Things (IoT) system for small or rural farmers using an optimization model to analyze data. In order to reflect a real-world scenario, we are also employing AI and ML in this; the model will be scenario based.

Table 2: Comparative Table Data Analytics Algorithm

Sr. No	Themes	Optimization Algorithm
1	Data Integration	Bayesian Networks, Support Vector Machines (SVM), Random Forest, Deep Learning approaches (e.g., CNN, LSTM)
2	Standardization	IoT protocols (e.g., MQTT, CoAP, HTTP), Data exchange formats (e.g., JSON, XML), RESTful APIs
3	Scalability	Genetic Algorithms, Particle Swarm Optimization, Ant Colony Optimization
4	Environmental Monitoring	Life Cycle Assessment (LCA), Carbon Footprint Analysis, Sustainable Re- source Allocation Models
5	Farmer	Adoption Technology Acceptance Model (TAM), Diffusion of Innovations theory, Behavioral Economics models
6	K-means	The detection is 1.29kg/ha for alluvial soil, 2.19kg/ha for black soil, 1.39kg.ha for red soil

Using too many pesticides and fertilizers could result in a lower quality harvest production. As a result, soil nutrient monitoring is extremely difficult. Figure 1 illustrates the flow of the research methodology employed in the research. The literature review can be done by analyzing a few terms in conjunction with the amalgamation of IoT, Agriculture 4.0 – obstacles and hurdles, Agriculture 4.0, Implementation and endurance, Agriculture 4.0 Future, Smart agriculture system. For these terms Scopus and Google Scholar will be researched. Next, these keywords will be investigated in relation to the articles that have been collected. Furthermore, the gathered articles will be examined based on the challenges, barriers and future scope. This is how the literature review will be carried out in this study. The primary challenges will then be verified with the use of literature and expert opinion. The theoretical framework will be laid by these challenges. A case study and questionnaire-based survey will be conducted for the agriculture industry. Then the review of Agriculture 4.0 drivers, enablers, risk factors and barriers analysis are to be done. With the help of the above review and literature survey the research scope and problem definition is designed. In order to prepare the data for analysis in Agriculture 4.0, particularly in soil testing where precise and trustworthy data is critical, requires careful consideration throughout the second phase of exploratory analysis. Data transformation, data reduction, and data purification are just a few of the important steps in the process.

Data Cleaning

Extract Missing Values

Check the dataset for missing values and decide on an appropriate strategy to handle them. Missing values can distort analysis and lead to inaccurate results. Techniques like imputation or deletion of rows/columns with missing values can be applied in accordance with the nature and extent of missing data.

Outlier Detection and Handling

Identify and handle outliers that might be caused by errors in measurement or other anomalies. Outliers have the potential to markedly impact the statistical properties of the data and can lead to incorrect conclusions. Techniques like Z-score analysis or the inter quartile range (IQR) method can be employed to detect and manage outliers.

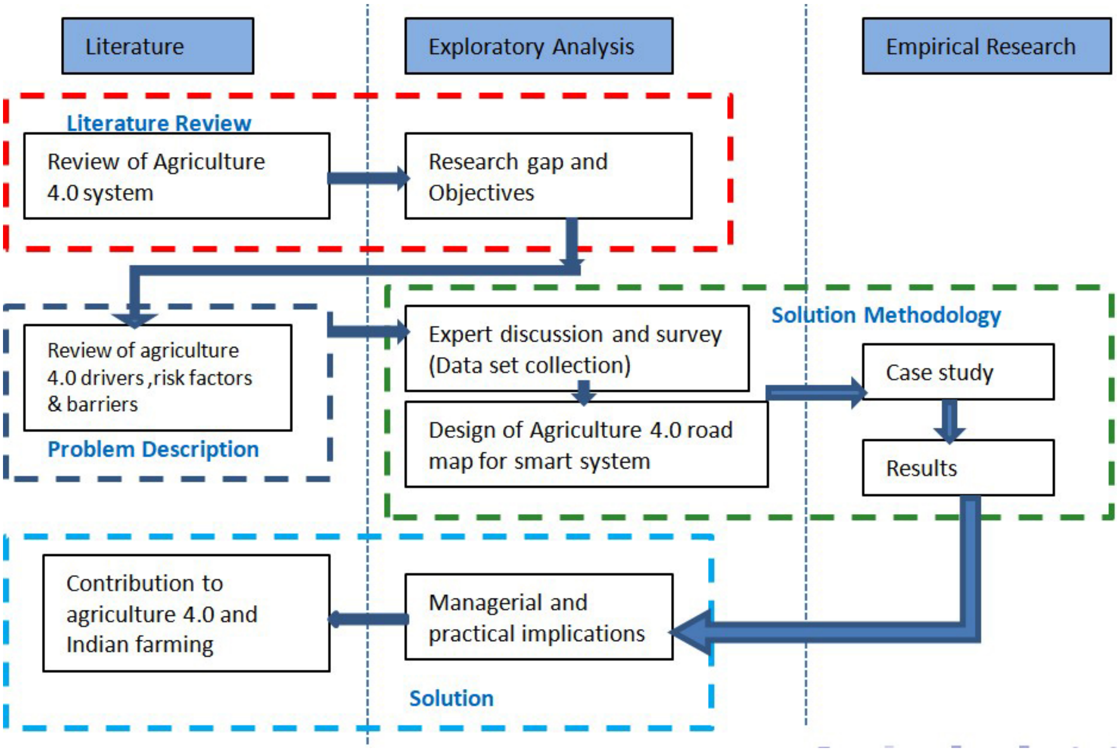

Fig. 1: Research Methodology Flow

Normalization/Standardization

Based on the algorithms used and models used, it might be necessary in order to set norms or regulate the data for bring all features to a common scale. This ensures that no single feature dominates the model training due to its scale.

Encoding Categorical Variables

If the dataset contains categorical variables, they require transformation into numerical representations for analysis. Techniques like one-hot encoding or label encoding can be applied.

Feature Engineering

To enhance the functionality of the model, add new features or change the ones that already exist. In the context of soil testing, this might involve aggregating or transforming certain soil characteristics to derive more meaningful features.

Data Reduction

Dimensionality Reduction

When a dataset has a lot of features, dimensionality reduction techniques like Principal Component Analysis (PCA) can be applied to reduce the number of features while keeping the majority of the data. This helps avoid the curse of dimensionality and speeds up the modeling process.

Feature Selection

Identify and keep only the most relevant features for analysis. Some features may not contribute significantly to the model's predictive power, and removing them can simplify the model without sacrificing accuracy.

In the context of Agriculture 4.0 and soil testing, the goal of data pre-processing is to guarantee the accuracy of the data, consistent, and suitable for the chosen analysis or modeling techniques. Properly pre-processed data enhances the effectiveness of models for machine learning and facilitates the extraction of meaningful insights for decision-making in precision agriculture.

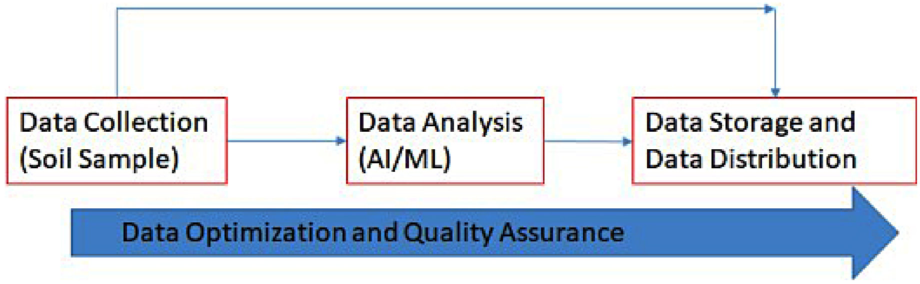

Fig. 2: Basic Flow of Work

Methodology

An integrated strategy that blends machine learning techniques or algorithms with IoT can improve the accuracy and resilience of data analysis for soil testing. When it comes to soil testing, we can consider combining the following methods.

Table 3: Hybrid Approach Analysis

Sr. No.	Journal Paper Reference	Hybrid Approach Component	Key Insights and Contributions
1	”Machine Learning Approaches for Soil Health Assessment in Precision Agriculture”,A. Smith[15] (2020).	Ensemble Learning	Demonstrates the effectiveness of ensemble methods (Random Forest, Gradient Boosting) in improving soil property prediction accuracy.
2	”Deep Learning Applications in Remote Sensing for Soil Property Estimation” ,B. Johnson,[17] (2019).	Deep Learning (CNN)	Highlights the use of Convolutional Neural Networks (CNNs) for analyzing remotely sensed soil data, improving feature extraction and classification from images.
3	”Reinforcement Learning for Optimal Resource Allocation in Precision Agriculture” ,C. Lee,[4] (2021).	Reinforcement Learning	Discusses the application of reinforce -ment learning, specifically Q- learning, for optimizing resource allocation e.g., irrigation and fertilization) in response to changing soil conditions.
4	”Fuzzy Logic-Based Soil Health Assessment in Uncertain Enviro-nments”.D. Gupta,[20] (2018).	Fuzzy Logic	Introduces a fuzzy logic-based approach to handle uncertain or imprecise soil data and incorporates expert knowledge to address ambiguity.
5	”Hybrid Genetic Algorithms for Feature Selection in Soil Property Prediction Models”.E. Wang,[21] (2018).	Hybrid Genetic Algorithms	Demonstrates the use of hybrid genetic algorithms for feature selection, which enhances model performance and interpretability in soil property prediction.

Integrating Machine Learning and Remote Sensing for Precision Soil analysis uses diverse techniques that can be integrated into a hybrid approach for soil testing data analysis. Integrating these methods can lead to more robust, accurate, and adaptive soil testing systems, contributing to sustainable and data-driven agricultural practices. The collection of soil report data sets in Agriculture 4.0 is vast, intricate, and challenging in conventional systems. In order to optimize the soil testing report, we must focus on four verticals. Volume, or the size of the data, Different data forms are called variety, streaming data analysis is called velocity, and data uncertainty is known as veracity.

The automatic monitoring of smart irrigation is revealed in figure 3, Sensor derived unstructured data can be fed into the process management unit, where it will be mapped and transformed into structured data. We can store this mapped structural information on Data Cloud as shown in figure. With the machine learning algorithms in data mining approaches that can be used with this organized data would yield significant data that farmers might utilize to forecast the ideal frame conditions. The hybrid approach for the soil testing with the help of machine learning and IoT can enhance the precision and robustness of soil testing data analysis.

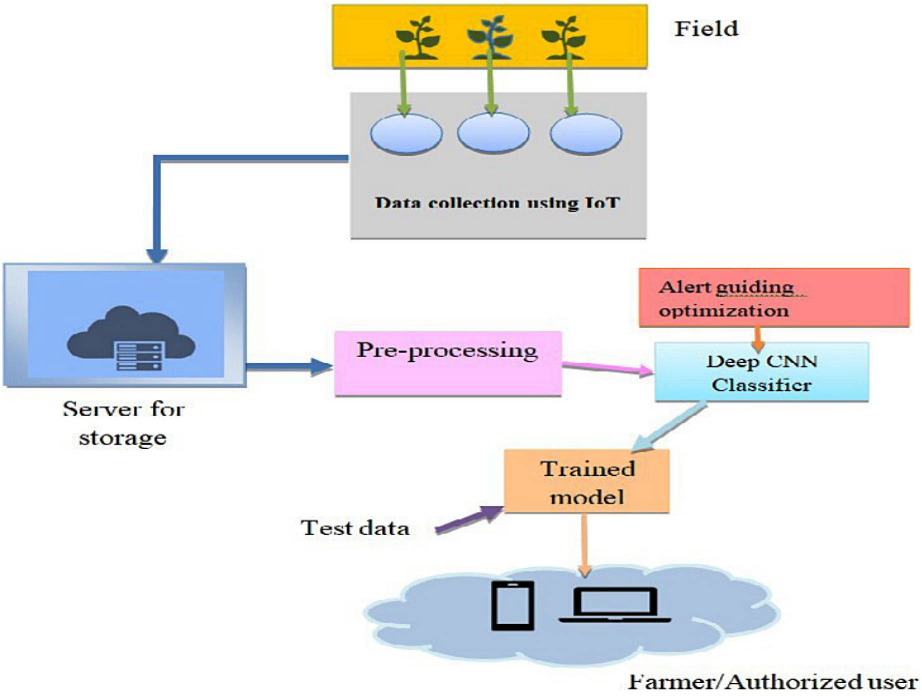

Fig. 3: Optimized approach for Agriculture 4.0

Water management and crop suggestion are the two main sources of intelligent irrigation techniques in the irrigation field. The Internet of Things (IoT) sensors are placed in the irrigation meadow to monitor the soil's pH, moisture level, and mineral content, including potassium, phosphorus, and nitrogen. After the nodes gather data from the irrigation grassland and convey it to the anchor nodes, the anchor nodes send the data back to the server for storage.

Through the anchor nodes, the server receives the moisture content of the soil that was acquired from the crop recommendation database. After that, the sent data is pre-processed to fill in any missing information from the database, improving the accuracy of irrigation with a sufficient supply of water. By keeping an eye on the moisture content, pH level, and minerals in the soil, alert guiding optimization maximizes the efficiency of the classifier by forecasting the appropriate amount of water needed for the agricultural area.

As illustrated by this research in precision agriculture and soil science, this analysis highlights the significance of a suggested strategy that incorporates machine learning and data analytic approaches.

Roadmap of Smart System

Integrating the Machine learning algorithm or methodology with IoT gets a full grasp of the IoT and machine learning landscape as it relates to soil testing. The figure 4 shows different blocks that are used in the smart soil testing system framework. Initially, the user must attend the optimization module in their implementation. The implementation with it provides the result in the feasibility for various sensors like temperature, pH or other proximal sensors. With the sensor, readout ckt is also implanted to build the electronic circuit system for smart agriculture soil testing application. For the execution of circuit and receive the various signals input from sensor analog switches and multiplexers is used. Calibration module is used with a threshold value to provide calibration input to the system circuit. The design conceptual model is obtained with the twining of Machine learning statistical methods and Microcontroller or embedded processor.

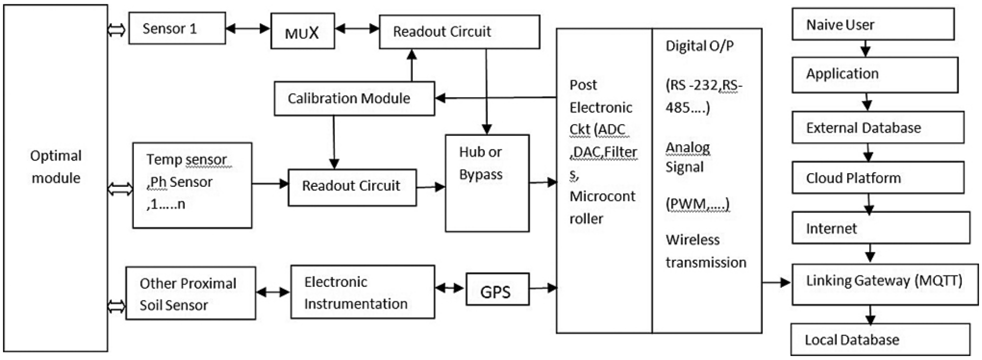

Fig. 4 : Roadmap for smart system

Algorithm and Result Analysis

This algorithm outlines the main components and steps involved in the hybrid approach, including data preprocessing, ensemble learning, deep learning, reinforcement learning, fuzzy logic, and hybrid genetic algorithms. After the execution of these components, the final evaluation and analysis stage allows for the assessment of model performance and the effectiveness of the hybrid approach.

For the result analysis with the help of hybrid approach in soil testing data analysis typically involves the following steps.

Steps for Proposed approach

Data Preprocessing

- Load and preprocess soil data
- Prepare soil images (if applicable)
- Split data into training and test

Deep Learning (CNN)

- Create and compile CNN model
- Preprocess and augment soil data
- Train CNN on data
- Make predictions for data

Hybrid Genetic Algorithms

- Optimize feature selection using hybrid genetic algorithms
- Select relevant features for modeling
- Train models with selected features

Evaluation and Analysis

- Visualize model outputs and results
- Calculate performance metrics

Dataset used to Train the Model

The soil testing dataset was used to evaluate the earlier proposed methods displayed below as reflected in the set.

- District soil survey and soil testing laboratory, dataset for Kalyan, Murbad, Bhivandi and Shahpur region dataset, 12 Attributes(3256 records).
- Crop recommendation dataset, From Krishikosh (Rahuri), 7 Attributes(2201 records)
- Fertilizer dataset ,From Krushi Kosh (Rahuri), 6 Attributes(521 records)

Metrics for Performance Analysis

Achievement metrics used for result evaluation are

Sensitivity

The sum of accurate positive classes predictions in the classification of crops and the prediction of minerals in the soil to the ratio of the sum of accurate predictions of positive classes and the misclassified classes as negative classes.

Specificity

The sum of accurate predictions of negative classes in the classification of crops and the prediction of minerals in the soil to the ratio of the sum of accurate predictions of negative classes and the misclassified classes as positive classes.

Accuracy

The ratio of the number of total test classes available to the sum of correct forecasts of positive and negative classes in the classification of crops and the prediction of soil minerals.

Experimental Results

In figure 4 a) blue dots show the experimental results of the IoT nodes that are initially placed in the environment for sensing. Figure 4 b) red and green dots show the data transfer to and from cloud and different IoT nodes.The experimental results shows the IoT nodes interactive performance for the temperature, humidity and soil moisture.

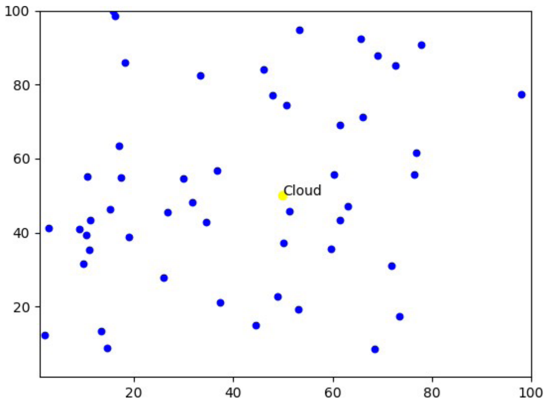

Fig. 4 a) : IoT nodes deployments

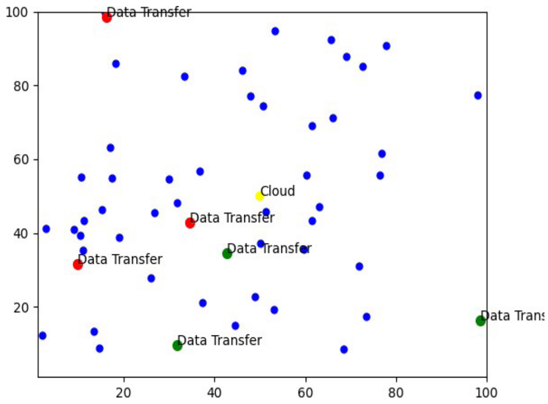

Fig. 4 b) : IoT nodes with data transfer

The hybrid approach for soil testing increases agricultural resistance to external shocks and fosters healthy plant growth by precisely watering crops and maintaining ideal soil moisture levels. This approach has been linked to reports of increased yields, improved crop quality, and reduced instances of crop loss as a result of crop and soil-related issues. All things considered, the implementation's outcomes highlight its potential to bring about revolutionary shifts in farming methods, opening the door for effective and sustainable food production systems. The specific analysis will depend on the goals of the soil testing project, the nature of data, and the performance criteria established. Regularly monitoring and analyzing the results are crucial for refining and optimizing the hybrid approach to achieve the best possible outcomes in precision agriculture and soil health assessment.

Conclusion

Agriculture 4.0 promotes the farming industry as a business opportunity, emphasizing the importance of modernizing agricultural processes to meet current market demands. Obstacles in predicting, mechanization, and communication face conventional farming. An improved irrigation and crop management system for agriculture is ensured by the use of data analysis by smart agricultural IoT systems. It is evident that the right architectural framework should be designed and implemented in order to manage data mining, data analysis, and appropriate decision-making services. With the integration of machine learning and data analysis methods like deep learning and genetic algorithms, the hybrid approach to soil testing data analysis provides a strong foundation for improving precision agriculture and sustainable soil health assessment. In this research proposed optimized approach with the continuous monitoring and soil testing for the precision farming is designed with following key points.

Enhanced Accuracy

The combination of multiple techniques like Deep CNN ,hybrid genetic algorithms improves the accuracy of soil property prediction and soil health assessment.

Resource Efficiency

With the help of various sensors, reinforcement learning enables efficient resource allocation, reducing water and fertilizer usage in agriculture. This contributes to cost savings and environmental sustainability.

Uncertainty Handling

Fuzzy logic provides a mechanism to handle uncertain or imprecise data, making soil testing more robust in real-world, dynamic environments.

Feature Selection

Use of genetic algorithms for feature selection enhance model interpretability and reduce dimensionality, resulting in more efficient models.

Integrated Decision-Making

Combining the outputs of different sensors provides a holistic approach to soil testing, allowing for more informed decision making in precision agriculture.

Future Scope

The prediction of soil properties and the evaluation of soil health are more accurate when IoT and machine learning approaches are combined. Various patterns in soil data can be captured with the aid of deep learning. For the future work, we focus on the deep learning algorithm and hybrid genetic algorithm and to work with diverse patterns in soil data.

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Conflict of Interest

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Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

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